The Permo-Carboniferous outcrops of the Gulf of Suez region, Egypt: stratigraphic classification and correlation

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ABSTRACT

The Permo-Carboniferous succession in the Gulf of Suez region is subdivided into: the Abu Thora Formation (Late Visean-Early Westphalian), the Abu Durba Formation (Middle Westphalian), and the Aheimer Formation (Late Westphalian/Stephanian-Early Permian). The Abu Thora and Abu Durba formations of Sinai are coeval with the Abu Da'ag Formation in the Northern Galala. The Aheimer Formation corresponds to the Ataqa Formation in the subsurface of the Gulf of Suez. These clastic-dominated deposits reflect shallow subtidal, prograding shoreline and fluviatile conditions. They overlie conformably open marine Early Carboniferous carbonates of the Um Bogma Formation and are overlain unconformably by continental red bed succession of Late Permian-Triassic age known as the Qiseib Formation. The whole Carboniferous-Permian succession in the region is bounded by two unconformities; a lower one resulted from the removal of the underlying Early Palaeozoic and the basal beds of the Early Carboniferous, and an upper one manifested by the partial erosion of the Permo-Carboniferous deposits from the area. Stratigraphic correlations with equivalent units recorded from the southern Peri-Tethyan basins indicate that great areas of North Africa and the Near East were situated near the southern margin of the Tethyan seaway during most of the Late Carboniferous-Early Permian time.

KEY WORDS
Peri-Tethys,
correlations,
Late Palaeozoic,
Gulf of Suez,
Near East.

RÉSUMÉ

Les affleurements d'âge carbonifère et permien de la région du golfe de Suez, Égypte : codification et corrélation stratigraphique. La succession permo-carbonifère dans la région du golfe de Suez est subdivisée en : la Formation Abu Thora (Viséen supérieur-Westphalien inférieur), la Formarion Abu Durba (Westphalien moyen) et la Formation Aheimer (Westphalien supérieur/Stéphanien-Permien inférieur). Les formarions Abu Thora et Abu Durba du Sinaï sont contemporaines de la Formation Abu Darag dans le Galala septentrional. La Formation Aheimer correspond à la Formation Ataqa en subsurface dans le golfe de Suez. Ces dépôts à dominance clastique reflètent des conditions subtidales peu profondes, ligne de rivage et fluviatile. Ils reposent en conformité sur les carbonates marins ouverts d'âge carbonifère inférieur de la Formation Um Bogma et sont recouverts en discordance par une succession continentale à bancs rouges du Permien supérieur-Trias, la Formation Qiseib. La succession permo-carbonifère de la région est limitée par deux discordances : l'inférieure qui résulte de l'érosion du Paléozoïque inférieur et des bancs inférieurs du Carbonifère inférieur et la supérieure qui se manifeste par l'érosion partielle du Permo-Carbonifère dans la région. Des corrélations stratigraphiques avec les bassins du domaine Sud péritéthysien indiquent que le Nord de l'Afrique et le Proche-Orient étaient situés près de la marge sud de la Téthys pendant le Carbonifère supérieur et le Permien inférieur.

MOTS CLÉS
Péri-Téthys,
corrélations,
Paléozoïque supérieur,
Golfe de Suez,
Proche-Orient.

INTRODUCTION

Of the Palaeozoic of Egypt, the Carboniferous-Permian rocks are sporadically exposed on both sides of the Gulf of Suez. Good outcrops are studied from west-central Sinai at Um Bogma, Wadi Feiran and Abu Durba, and west of the gulf in the Northern Galala, Abu Darag, Wadi Araba and in Wadi El-Dakhel (Fig. 1). Despite numerous investigations over the last century, stratigraphic correlations of the Late Palaeozoic successions in the region remained controversial and different lithostratigraphic schemes have been proposed by various authors (Fig. 2). The summary of stratigraphic subdivisions of the Palaeozoic rocks in Egypt outlined by Abdallah (1992) emphasises the great dispute between different authors concerning some of the rock units. The objective of this paper is twofold: (1) to bring together in a single document a comprehensive summary of what is now known of the stratigraphy of the Permo-Carboniferous rocks exposed in the Gulf of Suez region and to establish a unified stratigraphic scheme, and (2) to correlate this succession with synchronous units known from other countries in the Middle East. Much of the text is devoted to a systematic account of the stratigraphic classification of the Permo-Carboniferous in the area. Within individual stratigraphic units, local rock sequences are described and illustrated. These local sections are related to each other and to equivalent rock sequences outside the Gulf of Suez region to depict the distribution, lateral changes, age and gaps in the stratigraphic record necessary to untaveling the geologic history of the region.

The literature dealing with the subject has been recently reviewed and the history of the palaeontological research has been outlined by Kora (1995a, b). Therefore, only some significant publications are cited herein. Macrofloral elements are quoted from Lejal-Nicol (1990) whereas the microfloral assemblages are concluded from Kora (1993). Also, the micro- and macrofauna are summed up from the works of Kora (1989), Kora & Mansour (1991, 1992) and Kora (1992) which are utilizing some data from earlier literature. The present study has also gained much from the tectono-sedimentary synthesis and facies interpretations given by Issawi & Jux

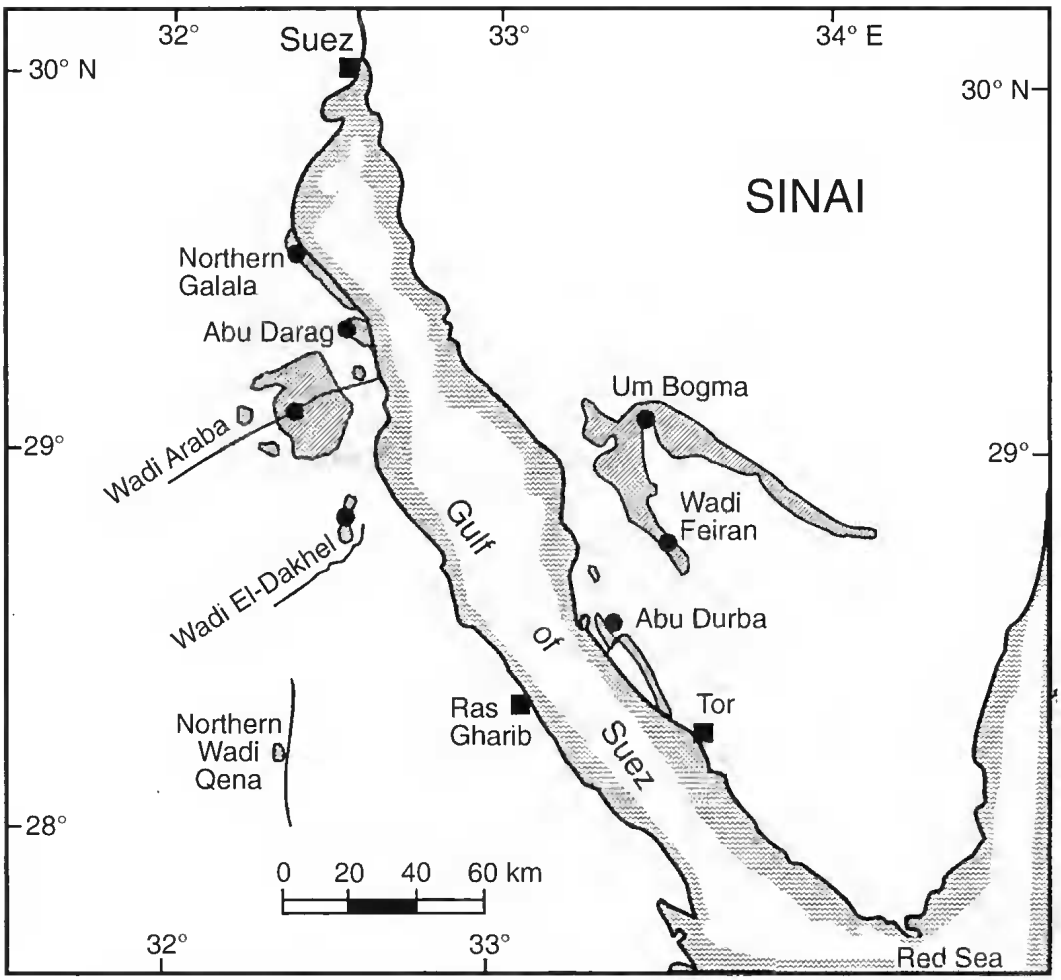

FIG. 1. — Location map of Permo-Carboniferous outcrops (hatched areas) in the Gulf of Suez region.

(1982), Jux & Issawi (1983), Keeley (1989), Abdallah *et al.* (1992), Darwish (1992), Weissbrod (1994) and Issawi (1996).

However, many gaps still exist and the present biostratigraphic zonation is only tentative. Obviously, these successions need to be closely investigated to look for more reliable fossils in these rarely fossiliferous clastic-dominated successions. Scattered land mines drifted in the area partly make it dangerous. Nevertheless, the dominant depositional environments could be concluded from macro- and microfacies interpretations. The biostratigraphy of the Early Carboniferous richly fossiliferous carbonates of Um Bogma Formation is not included in this study.

LITHOSTRATIGRAPHY

The Permo-Carboniferous succession exposed in the Gulf of Suez region consists mainly of sandstones and shales intercalating minor siltstones and sandy dolostones. In Sinai, this succession overlies conformably Early Carboniferous carbonate sequence known as the Um Bogma Formation. The Permo-Carboniferous deposits are overlain unconformably either by Permo-Triassic red beds of the Qiseib Formation or by Early Cretaceous pebbly sandstones of the Malha Formation.

The first priority of this study was to establish a reliable stratigraphy. The suggested lithostrati-

graphic scheme is fundamentally a compilation of the works of Abdallah & El Adindani (1965) and Kora (1992, 1995a, b). The stratigraphy adopted here is partly based on and supported by some palaeontological and palynological studies carried out by the author as well as other workers on the Palaeozoic of Egypt and adjacent countries. The Carboniferous clastic succession of Sinai is subdivided into the Abu Thora Formation and the overlying Abu Durba Formation. Equivalent rocks exposed on the western side of the Gulf of Suez are overlain by the Permo-Carboniferous Ahcimer Formation. The following comments summarize the characteristics of these lithostratigraphic units.

Abu Thora Formation

Nomenclature

This unit refers to the Late Carboniferous sandstone described by Ball (1916) from west-central Sinai. It was given different names including Ataka Series (Kostandi 1959), upper sandstone formation (Omara & Schultz 1965), Ataqa Formation (Weissbrod 1969; Said 1971; Klitzsch 1990), Ataqa Group – El-Hashash, Magharet El Maiah and Abu Zarab formations (Soliman & El Fetouh 1969) –, lower part of El Tih Sandstone (Omara 1971), Abu Thora Formation (Weissbrod 1980; Kora 1984) and Abu Thora Member of Rod El Hamal Formation (Beleity *et al.* 1986). In the Northern Wadi Qena-Wadi El-Dakhel, equivalent deposits were named Gilf Formation (Issawi & Jux 1982) and Somr El Qaa Formation (Klitzsch 1990).

Recently, the name Abu Thora Formation has gained wide acceptance and was subsequently used by most investigators, *e.g.* El Sharkawi *et al.* (1990), Morsy *et al.* (1992), Abdallah *et al.* (1992), El-Fawal (1994), Kora (1992, 1993, 1995a, b), El Agami (1996) and El Sherbini (1996).

Type section and locality

Wadi Abu Thora (lat. 29°02'N and long. 33°24'E), near Um Bogma, west-central Sinai with a thickness of 190 m. Weissbrod (1969) distinguished two members of the formation: a sandy-clayey member at base and a sandy-quartzitic member at top.

Reference sections

Abu Rodeiyim boreholes on the southern side of Wadi El Hommur, north of Um Bogma (200 m thick). A second reference section is measured near Wadi Sidri (80 m thick) and a third one (68 m thick) is studied from Wadi Nidia El Samra on the southern side of Wadi Feiran. A fourth less developed reference section (50 m thick) is recorded from Gabal Ekma in the Abu Durba area (Fig. 3).

Boundaries

In the Um Bogma area, the Abu Thora Formation overlies conformably the Early Carboniferous dolostones of Um Bogma Formation and underlies unconformably the Permo-Triassic red beds of Qiseib Formation with a local basaltic intrusion in-between. The basaltic rocks of Farsh El-Azraq, Wadi Abu Natash and Wadi Budra are related to Early Triassic-Middle Jurassic volcanic phases (Weissbrod 1969; Saleeb-Roufaiel *et al.* 1989).

In Abu Durba and Wadi Nidia El Samra to the south of Wadi Feiran, the Abu Thora Formation overlies unconformably Early Palaeozoic sandstones with a thin conglomeratic bed at the contact. In that particular area, the formation is overlain conformably by the Carboniferous shaly succession of Abu Durba Formation (Fig. 3). In Wadi El-Dakhel of the north Eastern Desert, the Abu Thora Formation is unconformably overlain by Early Cretaceous clastics of the Malha Formation (Fig. 4), reflecting a wider time gap of the unconformity than that present in the type area (Abdallah *et al.* 1992).

Description

This is a dominantly light-coloured sandstone succession with occasional dark brown and yellowish brown layers, alternating with silty shales and kaolinitic claystones, carbonaceous in places. The formation could be subdivided into a lower "kaolin/coal-bearing" member and an upper "glass sand" member.

The lower member is distributed all over west-central Sinai, decreasing in thickness from 140 m in the Um Bogma area to about 70 m in the Wadi Feiran area and 50 m in the Abu Durba area (Fig. 3). This member is made up of pinkish

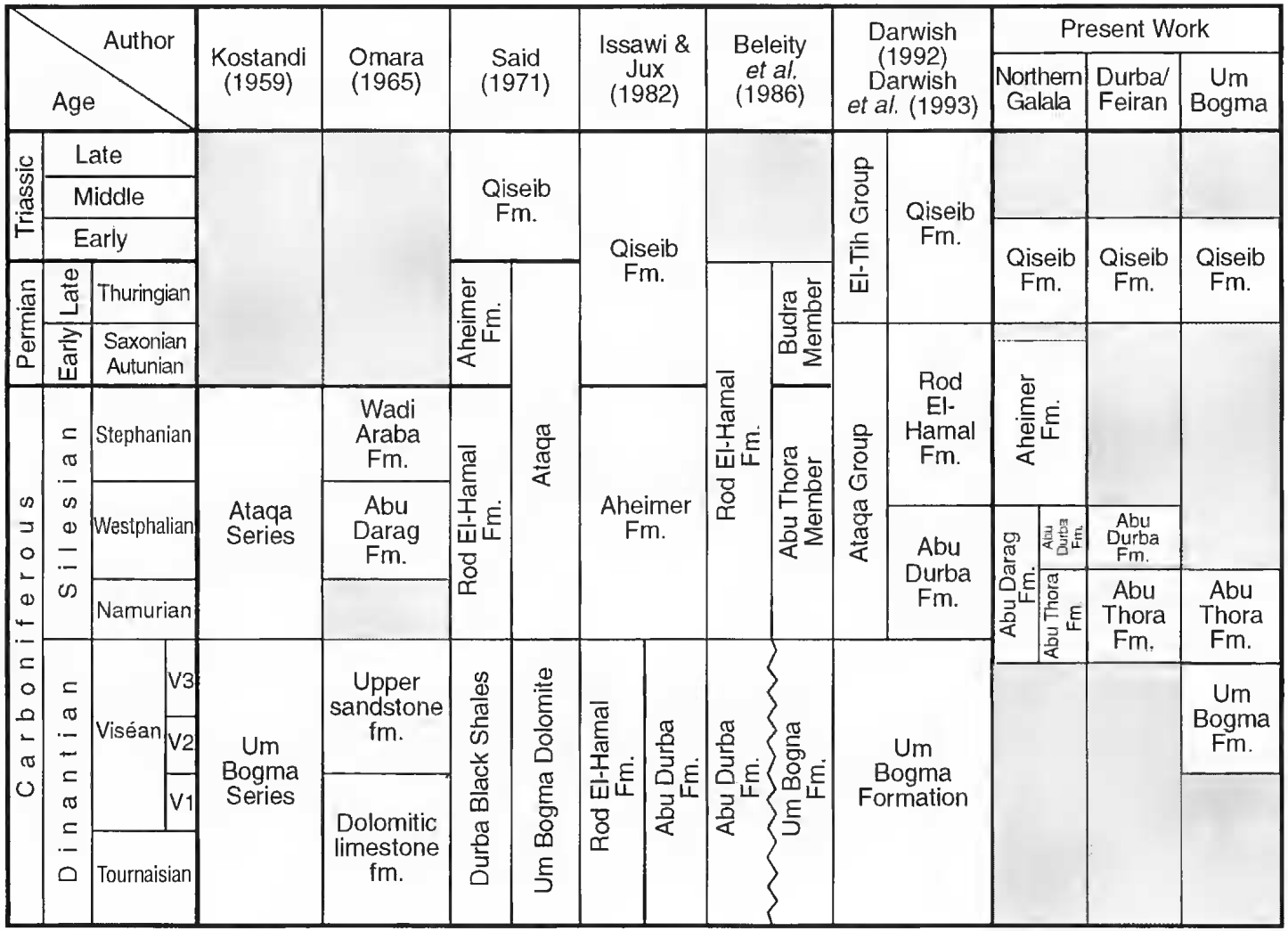

FIG. 2. — Stratigraphic classification schemes used for the Late Palaeozoic succession in the Gulf of Suez region.

white and yellow thick-bedded sandstones intercalating some mudstones and shales. Cross bedding, mainly of the tabular-planar type, but also wedge and convolute bedding are observed. The planar sets are 50-100 cm in thickness, 2-3 m in length and generally dip 20°-30° towards north. Ripple marks and flat horizontal laminations are observed in the fine silty intercalations near the top of the member. At Wadi Nidia El Samra to the south of Wadi Feiran, the basal part of this member includes 3 m thick biturbated shale layer overlying directly the conglomeratic band separating the Abu Thora Formation from the Early Palaeozoic clastics.

Two carbonaceous shale horizons with coal streaks were recorded from the continuously cored succession of the Abu Rodeiyim boreholes in the northern Um Bogma area. The lower level is about 17 m thick directly overlying the marly dolostones of Um Bogma Formation. A kaolinitic claystone bed (3 m thick) is recorded in an interval about 20 m above it. The upper carbonaceous shale bed is 100 m above the lower one. It varies in thickness between 3 and 20 m and is underlying directly the upper "glass sand" member. At Wadi Abu Thora, the lowet carbonaceous shale intercalation (9 m thick) appears some 70 m above the Um Bogma dolostones and the upper clay is 30 m above it. The kaolin beds exploited at Wadi Khaboba and Gabal Hazbar in the Um Bogma area are stratigraphically lower than that in Wadi Sidri area. This indicates that the kaolinitic claystones and carbonaceous shale horizons in the Abu Thora Formation are not confined to a certain level in the formation.

The sandstone-kaolinitic mudstone facies of the lower member of Abu Thora Formation in the Um Bogma and Wadi Feiran areas yielded badly preserved brachiopods and marine ichnofossils indicating a remnant of the shallow marine conditions that prevailed earlier in the Carboniferous duting deposition of the Um Bogma carbonates. The carbonaceous shale horizons yielded lepidodendroid flora and miospores of pteridophytic affinity. Thus, the litho- and biofacies encountered reflect gradational environments between coastal marine, swampy deltaic and fluviatile (Fig. 5).

The upper "glass sand" member is recorded essentially from the central and northern parts of the Um Bogma area with an average thickness of 60 m. Glass sand is currently exploited at Um Rodeiyim, El Qor and Wadi Khaboba. It is also quatried from the notthern Wadi Qena-Wadi El-Dakhel stretch in the Eastern Desert. This member was not recorded from Wadi Feiran and Abu Durba areas due to erosion or even non-deposition. The quarried white sand interval is usually in the range of 4-10 m of friable clean well-sorted and rounded medium to fine grained quatzitic sandstone. Many sandstone beds are structureless, deeply weathered and contain neither clays nor carbonates, but enclose some granules and coarse sand grains. The white sandstones are in places irregularly- to tabular-planar cross bedded. Badly preserved moulds and casts of indeterminate pelecypod and brachiopod remains were recorded from the weakly consolidated bioturbated sandstones of Wadi Khaboba near Um Bogma and Wadi El-Dakhel in the northern Eastern Desert, reflecting the dominance of marginal marine and fluviatile depositional environments.

Fossil content and age

The Abu Thora Formation contains faunal and floral elements. A Late Visean-Early Namurian marine macroinvertebrate fauna including the brachiopod *Orthoteres subglobosus* Girty (Fig. 5) and the hydrozoan *Plectodiscus* sp. was described from the kaolinitic mudstone horizon at Wadi Khaboba in the Um Bogma area (Kora 1992). A marginal marine thanatocoenosis was recorded from the white sandstone of Wadi El-Dakhel in the north Eastern Desert (Jux & Issawi 1983). Most common is the brackish to fresh-water pelecypod *Anthraconaia* Trueman *et* Weir; next comes typical marine molluscs (*Bellerophon* Montfort, *Cypricardella* Hall, *Edmondia* De Koninck, etc.) and rare brachiopods (*Dictyoclostus* Muir-Wood, *Schizophoria* King and *Rhipidomella* Oehlert).

In the Wadi Feiran area, the Abu Thora Formation has yielded a broad variety of trace fossils of which three forms do have stratigraphic potential: *Cruziana carbonaria* Seilacher, ?*Cruziana costata* Seilacher and *Margaritichnus reptilis* (Bandel). According to Seilacher (1990),

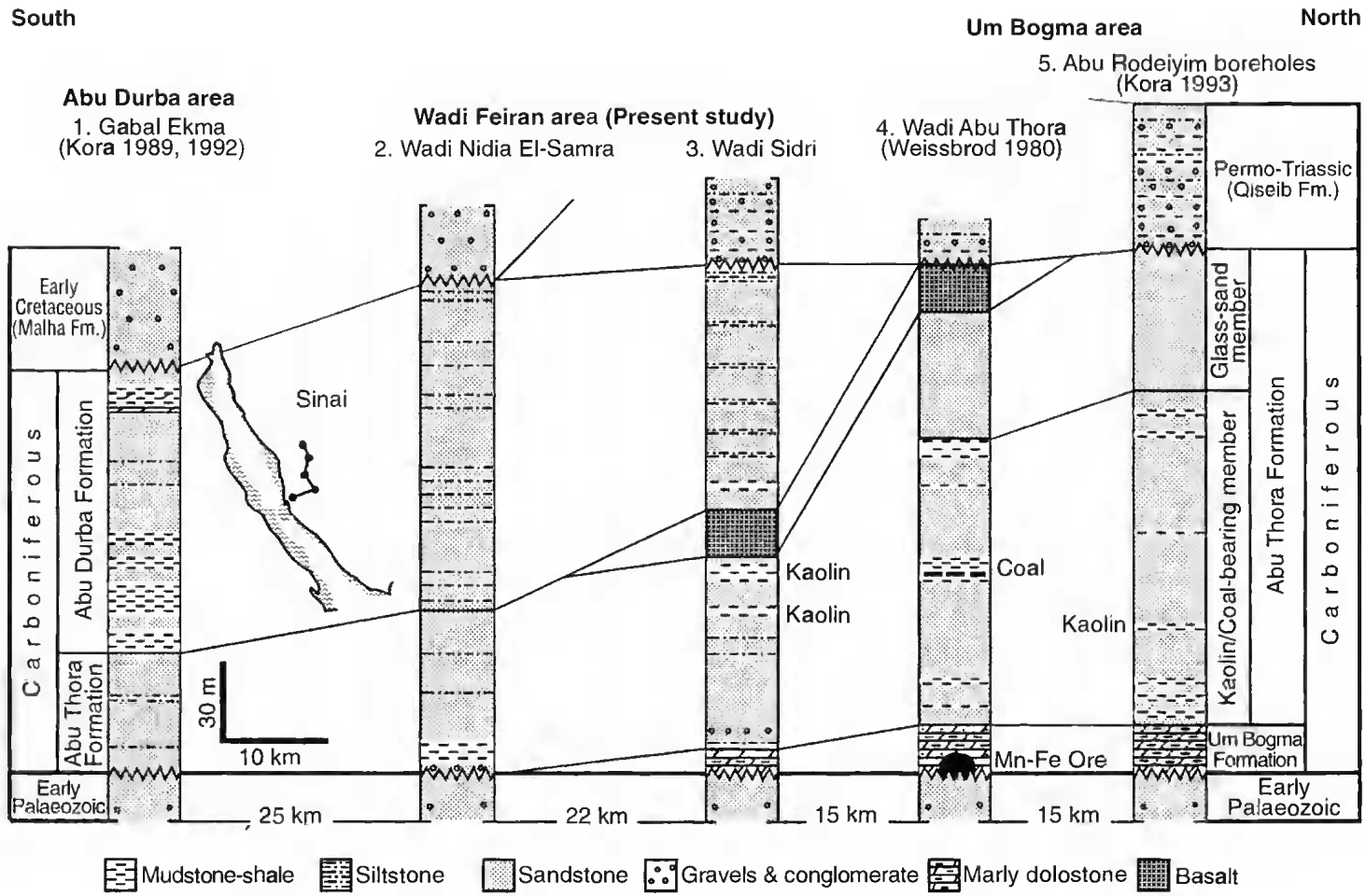

FIG. 3. — Stratigraphic correlation chart of the Carboniferous successions in south-western Sinai.

the *Margaritichnus* specimen from Sinai is identical in form and size with material from the Late Carboniferous of North America.

In the Um Bogma area, the argillaceous horizons of the Abu Thora Formation yielded rare finely agglutinated to granulated calcareous foraminifers belonging to species of *Lugtonia* Cummings, *Nodosinella* Brady and *Earlandinita* Cummings which range through most of the Carboniferous. However, an archaediscid foraminiferal assemblage was described from equivalent deposits included in the basal part of the Abu Darag Formation on the western side of the Gulf of Suez (Kora 1995b). The fossil spectra in that interval include *Archaediscus karreri*, *A. spira*, *A.* ex gr. *akchimensis* and *Asteroarchaediscus* ex gr. *rugosus*, pointing to a latest Visean-earliest Namurian transition.

Plant remains have long been known from the Abu Thora Formation (Fig. 5). These consist essentially of stem, root and leaf impressions of *Lepidodendron*, *Lepidodendropsis*, *Lepidophloios*, *Knorria*, *Sigillaria*, *Calamites*, *Bathrodendron*, *Noeggerathia*, etc. and were recorded mainly from the Um Bogma area in Sinai. Seward (1932) reported that the Sinai fossils might belong to a flora that flourished not far from the southern shore of the Tethys Sea in the latter part of the Early Carboniferous or in the early stages of the Late Carboniferous. Similarly, Lejal-Nicol (1990) concluded a Late Visean-Namurian age for a similar assemblage recorded at Wadi Mukattab in the Wadi Feiran area.

Palynomorphs were repeatedly recorded from the Abu Thora Formation. Recently, Kora (1993) described two miospore assemblages from the carbonaceous shale horizons intercalating the lower member of the formation in the Abu Rodeiyim boreholes. Assemblage Zone A is restricted to the basal part of the formation and is characterised by the common presence of *Raistrickia nigra*, *Spelaeotriletes oweusi*, *Dibolisporites montuosus*, *Retusotriletes incohatus* and *Vallatisporites ciliaris* suggesting a Late Visean age. Assemblage Zone B is restricted to the 20 m interval just below the glass sand member with a rich microflora including *Raistrickia fulva*, *Laevigatosporites vulgaris*, *Endosporites globiformis*, *Lophotriletes gibbosus* and *Verrucosisporites donarii* indicating an age ranging from Namurian C to Westphalian A.

Geographic distribution and local correlation

The Abu Thora Formation is widely distributed in the Gulf of Suez region. In west-central Sinai, it is best developed in the central and northern parts of the Um Bogma area where it attains its maximum thickness (200 m). It extends from Wadi El Hommur and the upper reaches of Wadi Khaboba, covering the broken plain of El Qor, and stretches across Gabal Hazbar and Gabal Ghorabi but decreases to a thickness of 60 m in Gabal Raqaba eastwards. It is also well exposed in a rather narrow strip extending southwards through Wadi Budra, Wadi Sidri, Wadi Mukattab and crossing Wadi Feiran to Wadi Nidia El Samra. The Abu Thora Formation is reduced in thickness to about 50 m in the Abu Durba area (Fig. 3).

In the western side of the Gulf of Suez, the Abu Thora Formation as described herein, corresponds to the lower member (50 m thick) of the formation described by Abdallah *et al.* (1992) from Wadi El-Dakhel in the environs of Southern Galala. Their upper member (20 m thick) is mostly coeval with the Abu Durba Formation described below. Similarly, the lower two units (100 m thick) of the Abu Darag Formation (Abdallah & El Adindani 1965) are timewise equivalent to the present Abu Thora Formation; the overlying two units (75 m thick) represent essentially the shaly succession of the Abu Durba Formation. Moreover, equivalent deposits to the Abu Thora Formation were penetrated by drilling in Wadi Araba borehole-1, represented mostly by unit 3 of Hermina *et al.* (1983). This interval corresponds to the upper part of Nubia "C member" in the classification adopted by oil companies for the Gulf of Suez wells.

Abu Durba Formation

Nomenclature

A formation status for this unit was introduced by Said (1971) who named it Durba Black Shales or Durba Formation (166 m thick), after a lithologic description given by Hassan (1967) to a 122 m thick sandstone and fossiliferous

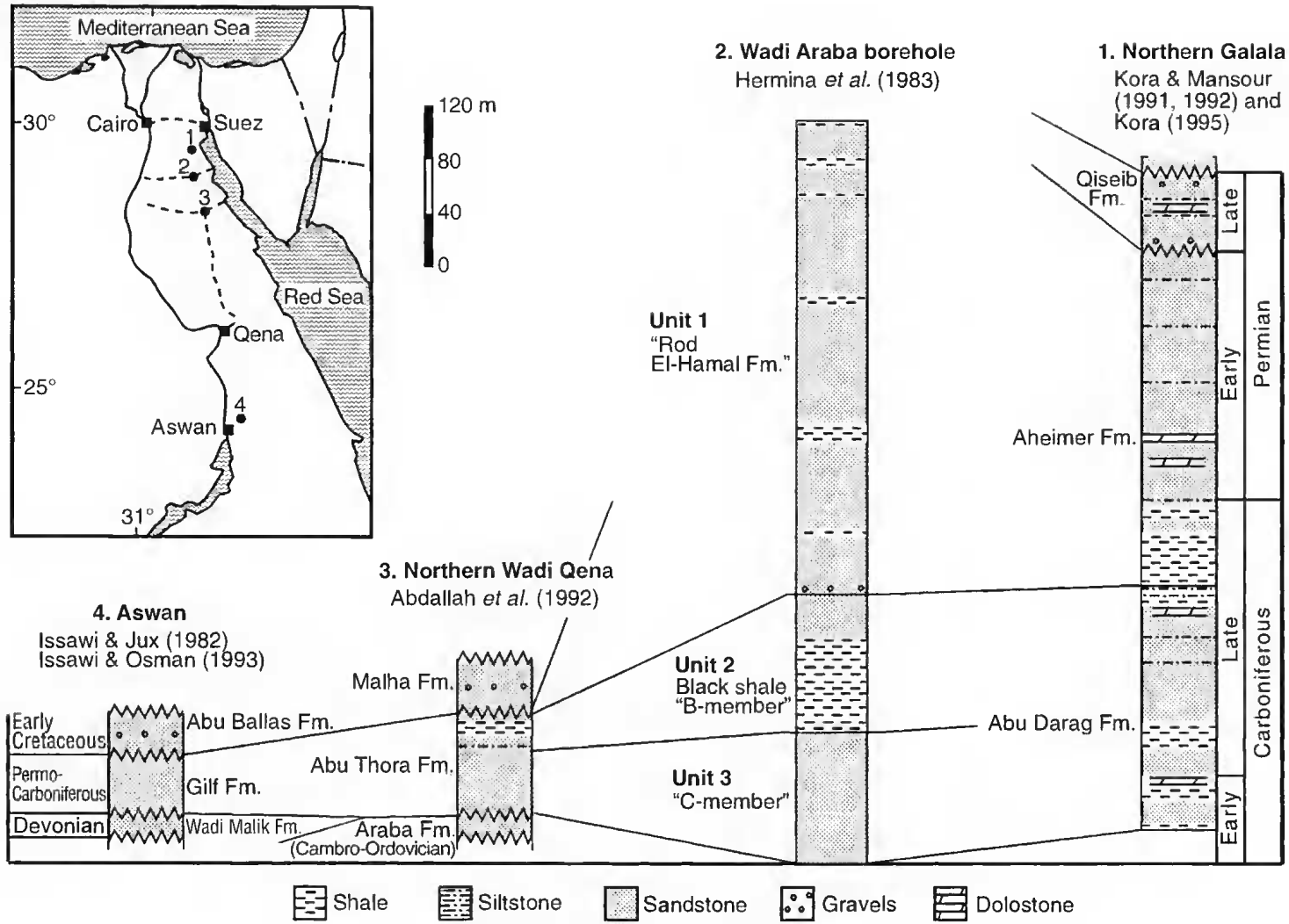

FIG. 4. — Stratigraphic correlation chart of the Carboniferous-Permian successions in the Eastern Desert of Egypt.

shale succession exposed in the Abu Durba area, Sinai. It is a synonym with the Nubia "B member" of the oil companies classification. This unit was incorrectly referred to as Aheimer Formation by Weissbrod (1980), Issawi & Jux (1982) and Allam (1989). Currently, the name "Abu Durba Formation" is commonly used by most investigators (Klitzsch 1990; Kora 1989, 1992; El Agami 1996; El Sherbini 1996 and Issawi 1996).

Type section and locality
East of El Belayim Bay, in the vicinity of Gabal Abu Durba, southwestern Sinai (lat. 28°34' N and long. 33°17' E). Another minor locality was also found near the mouth of Wadi Feiran on the eastern coast of the Gulf of Suez (Hassan 1967).

Reference sections
Two sections were studied from the type area (Kora 1989). The first (125 m thick) extends through the southern slopes of Gabal Ekma, immediately to the east of El Belayim Bay. The other section (120 m thick) was studied on the right hand side at the entrance of Wadi Feiran, facing the Petrobel oil fields. Two additional sections are studied throughout the present work in the Wadi Feiran area. The first (105 m thick) is measured near Wadi Sidri at its junction with the southern Wadi Budra. The second (140 m thick) was collected from Wadi Nidia El Samra near the contact with the basement rocks on the southern side of Wadi Feiran (Fig. 3).

Boundaries
In the type area and to the south of Wadi Feiran, the Abu Durba Formation overlies conformably the Abu Thora Formation and is unconformably overlain by Early Cretaceous pebbly sandstones of the Malha Formation. To the north of Wadi Feiran, near Wadi Sidri and Wadi Budra, the Abu Durba Formation is separated from the Abu Thora Formation by a basaltic sill and is overlain by the Permo-Triassic red beds of the Qiseib Formation (Fig. 3). In Wadi Araba borehole-1 on the western side of the Gulf of Suez, the Abu Durba Formation (unit 2 of Hermina *et al.* 1983) is underlying conformably a Late Carboniferous succession referred to as Rod El-Hamal Formation. In the Abu Darag area, deposits equivalent to the Abu Durba Formation which are represented by the upper two units of the Abu Darag Formation (Abdallah & El Adindani 1965) are overlain unconformably by Permo-Triassic red beds of the Qiseib Formation. At Wadi El-Dakhel in the northern Eastern Desert, rocks equivalent to the Abu Durba Formation (upper member of the Abu Thora Formation of Abdallah *et al.* 1992) were overlain unconformably by the Malha Formation (Fig. 4).

Description
In the Abu Durba area, the formation could be differentiated lithologically into three horizons (Fig. 3). The lower part is made up of dark grey to black shales interbedding few laminated siltstone and thin-bedded grey sandstone beds. An environment dominated by brackish water or estuarine conditions is indicated from the presence of only arenaceous foraminifers of low diversity (Fig. 5). The middle part is essentially composed of white or multicoloured medium to coarse grained sandstones ranging from thin bedded to tabular-planar cross bedded. The tabular sets are 20-30 cm in thickness and 3-4 m in length. The upper part of the formation is characterised by the presence of a dark grey to green fossiliferous shale horizon with two sandy dolostone/dolomitic sandstone interbeds. The shale contains varied marine fauna dominated by bryozoans and brachiopods. A conspicuous unfossiliferous reddish brown fine sandstone bed separates the Abu Durba Formation from the overlying light-coloured Cretaceous sandstones of the Malha Formation in that area. However, in the Wadi Feiran area, the differentiation of the Abu Durba Formation into three parts is not possible, since the dark grey siltstone and shale beds alternate with the ferruginous sandstones throughout the whole succession. Also, the fossiliferous marine sandy dolostone interbeds are not encountered (Fig. 3).

Fossil content and age
The lower part of the Abu Durba Formation in the type area is characterised by an assemblage of arenaceous foraminifers dominated by *Glomospira diversa* Cushman *et* Waters and *Nodosinella aegyptiaca* Said *et* Eissa (Fig. 5).

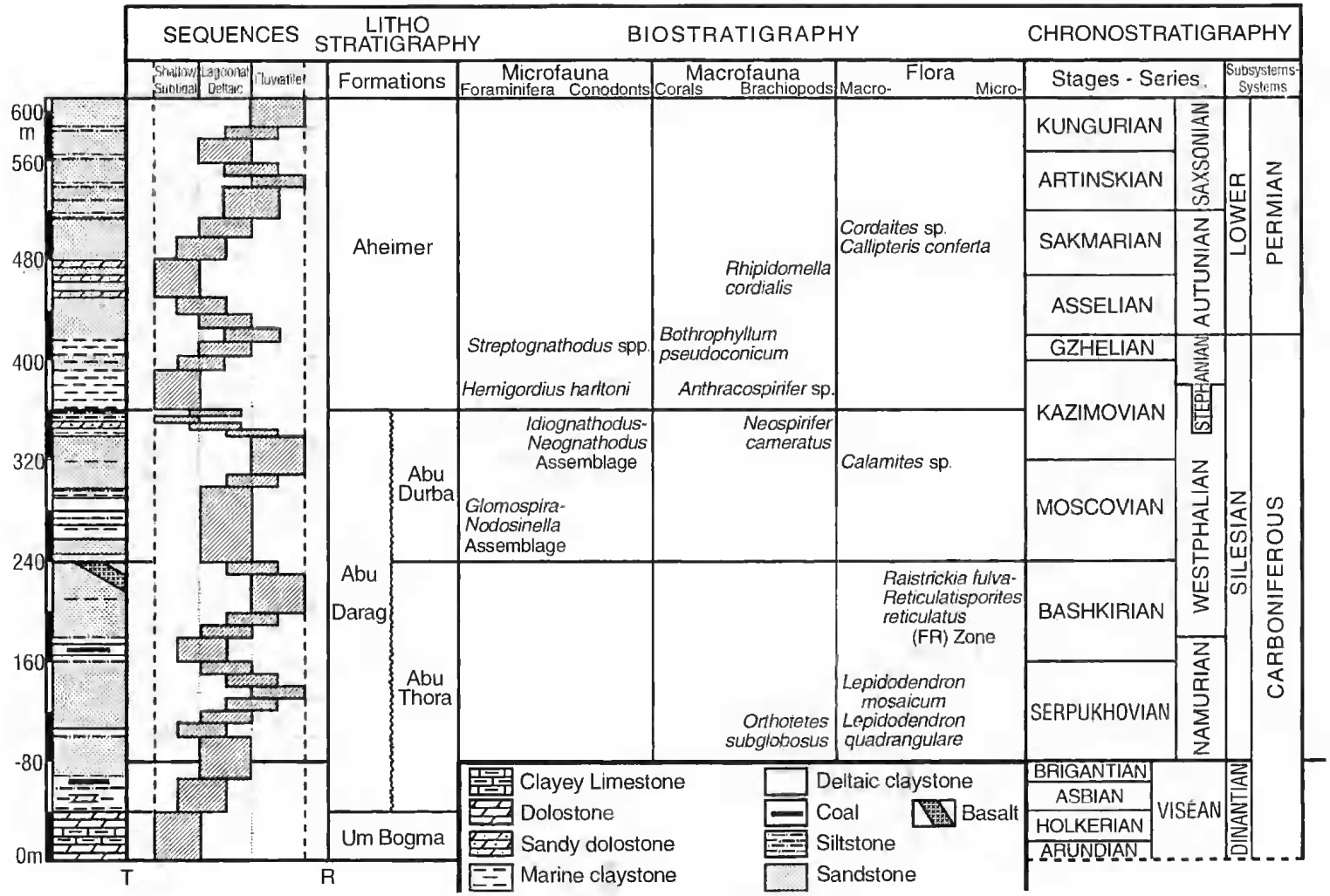

FIG. 5. — The Late Carboniferous-Early Permian stratigraphic sequence in the Gulf of Suez region (the biostratigraphy was compiled from different sources mentioned in the text).

Similar foraminiferal association is encountered from the succession studied at Wadi Sidti. Plant remains in the form of drifted logs of *Lepidodendron* and *Calamites* were recorded from the middle sandy interval of the formation, whereas bryozoans cover almost the entire bedding plane surfaces of some shale beds in the upper part and include species of *Fenestella*, *Polypora*, *Fistulipora* and *Ascopora*. These are associated with the Middle Pennsylvanian brachiopod *Neospirifer cameratus* (Morton) together with species of *Reticulatia*, *Choristitella* and *Choristites*. Bryozoans and brachiopods of similar affinity were recorded from the Wadi Araba borehole-1 (Hermina *et al.* 1983). This interval is characterised by the presence of a conodont assemblage dominated by *Idiognathodus delicatus* Gunnel and *Neognathodus medexultimus* Merrill (Fig. 5), suggesting an Early Moscovian age equivalent to Westphalian B-C (Kora 1989).

Geographic distribution and local correlation

The Abu Durba Formation is recorded from both sides of the Gulf of Suez. On the eastern side, it is well-developed and best exposed in the Abu Durba-Wadi Feiran area, particularly along the western slopes of Gabal Ekma. It is not encountered in the central and northern parts of the Um Bogma area (Fig. 3). This fossiliferous mainly black shale succession is described from Wadi Araba borehole-1, on the western side of the gulf (Said 1971; Hermina *et al.* 1983). It has been also recorded from many wells drilled by oil companies in the Gulf of Suez, *e.g.* in the Gharib, Bakr Ramadan, July, Ras Budran and Belayim oil fields, and is usually referred to as Nubia "B member".

The present study considers the fossiliferous dark coloured upper part (20 m thick) of the Carboniferous succession exposed at Wadi El-Dakhel in the northern Eastern Desert overlying the workable glass sand (the upper shale-sandstone member of the Abu Thora Formation of Abdallah *et al.* 1992) to represent the Abu Durba Formation in that area. Deposits equivalent to the Abu Durba Formation do occur in the Abu Darag area and are included in the upper part (75 m thick) of the Abu Darag Formation of Abdallah & El Adindani (1965). This interval yielded Westphalian microfossils (Omara 1965). However, the succession cannot be collected from a single outcrop. The complicated fault pattern and the wide distribution of Plio-Pleistocene terraces in the Abu Darag-Wadi Araba area make the distinction between the clastics building up the Abu Thora and the Abu Durba formations rather arbitrary. The present study suggests to keep applying the name Abu Darag Formation for the Carboniferous succession exposed around the Abu Darag Lighthouse in the Northern Galala which is equivalent to both the Abu Thora and the overlying Abu Durba formations in Sinai (Figs 4, 5).

AHEIMER FORMATION

Nomenclature

This unit was first named by Abdallah & El Adindani (1965), coeval with the Ataqa Formation (Said 1971; Beleity *et al.* 1986) and with the upper part of the Ataqa Group or the Rod El Hamal Formation as used by Darwish (1992).

Type section and locality

Wadi Aheimer, about 10 km S-SE of Ain Sukhna on the eastern footslopes of the Northern Galala massif (lat. 29°31' N and long. 32°29' E); the thickness is approximately 250 m. It was subdivided into 3 units; a lower unit: Shale member (60 m), a middle unit: Limestone member (90 m) and an upper unit: Silt-sandstone member, 100 m thick (Said & Eissa 1969; Said 1971).

Reference sections

The Aheimer Formation is studied by the present writer in the cliffs bordering Bir Aheimer between road marks 67 and 68 km of the Suez-Gharib road (162 m thick); another reference section is well exposed at road mark 79 km. The formation ranges in thickness from 65 m around Wadi Qiseib to more than 200 m slightly to the south of Ain Sukhna. The thickness of these highly faulted sequences varies greatly from place to place within short distances.

Boundaries

In the study area, the base of the Aheimer Formation is not exposed, but it has been considered

to rest conformably over or to interfinger with the Abu Darag Formation (Klitzsch 1990) or the Rod El Hamal Formation (Said 1971). It underlies without visible unconformity the Permo-Triassic red beds of the Qiseib Formation. In places where the red beds were removed, *e.g.* on the northern footwalls of Wadi Aheimer and the northern face of Northern Galala, the Aheimer Formation is overlain unconformably by the Early Cretaceous Malha Formation (Swedan & Kandil 1990; Darwish 1992).

Description

The Permo-Carboniferous exposures in the Northern Galala form a narrow strip of dark-coloured sandstones alternating with a number of fossiliferous shale and dolostone beds, often in a cyclic manner. Several fining upward sequences of 10-20 m thickness were described by Bandel & Kuss (1987). Fluviatile sandstones commonly form the base of the cycle while the top is dominated by mudstones and dolomitized limestones with diverse shallow marine fauna. It can be subdivided into three members (Kora & Mansour 1992).

Lower member

This member is composed mainly of dark grey-black fossiliferous papery shales. They are slightly calcareous and intercalated with some yellow calcareous sandstone beds. It is most thick (60 m) south of Bir Abu Darag. About 34 m of this unit are exposed in the cliffs overhanging the asphaltic road of Suez-Gharib in two localities studied at road marks 68 and 79 km. The basal shales are rich in crinoidal columnals, bivalves, corals, brachiopods and bryozoans, reflecting shallow normal marine conditions. A low energy environment is suggested by the presence of delicate fenestrate bryozoans as well as the preservation of most crinoids in growth position. Trace fossils in the form of simple vertical and deep burrows are frequently encountered in the silty shale facies near the top of this member, indicating a marginal "intertidal" environment. So, a sheltered shallow marine environment changed to intertidal "lagoonal-deltaic" conditions during the deposition of the upper part of the lower member (Fig. 5).

Middle Member

This unit is made up of yellowish brown sandstones intercalated with few grey siltstone and calcareous sandstone beds. Along the measured section at road mark 68 km three to four thin hard brown crinoidal dolostone beds are encountered in this member which yielded some thin shelled brachiopods. According to Abdallah & El Adindani (1965), this member is best developed (106 m thick) in the cliffs that border Wadi Aheimer. There, it is characterised by the presence of six crinoidal limestone horizons and five fossiliferous sandy limestone beds. These rocks are associated with sandstones showing common small-scale herringbone cross bedding. The angle of inclination is 15-20° in two opposite directions forming chevrons. This suggests a partly intertidal depositional environment for the basal and top beds of this member. The characteristic microfacies of this member is an alternation of calcareous siltstone, sandy crinoidal dolostone and dolomitized algal grainstone. Within the carbonate facies, characteristic thali of encrusting phylloid (leaf-like) algae have been observed associated with rare calcareous foraminifers. These dolostone thin beds have yielded thin-shelled brachiopods together with other shell fragments in a clean, grain-supported fabric. This association indicates deposition in a shallow, well-lighted subtidal environment (Fig. 5).

Upper member

This member is composed of yellow-grey thick-bedded fine-medium grained sandstones with few light to dark grey siltstone interbeds. The unit attains an average thickness of 100 m at Wadi Aheimer. It thins to only 40 m in the northern face of the Northern Galala. Tabular-planar cross bedding is the dominant sedimentary structure observed. The sandstones are mostly quartz arenite, partly ferruginous and partly argillaceous. Rare badly preserved agglutinated foraminifers are the only microfossils which could be separated from the intercalating silt-shale horizons. These indicate a marginal environment containing some brackish lagoons and swamps. This environment might have been changed to fluviomarine conditions near the base and top of the succession (Fig. 5), where large-

scale tabular bedding is more conspicuous in coarse ferruginous pebbly sandstones.

Fossil content and age

The Permo-Carboniferous succession of the Aheimer Formation yielded a variety of macro- and microfaunal and floral associations. The lower member is the richest fossil-bearing horizon encountered. It yielded an interesting rugose coral fauna described by Herbig & Kuss (1988) and Kora & Mansour (1991). The coral fauna includes typical Late Carboniferous "Westphalian D-Stephanian" forms e.g. *Roti-phyllum sokolovi* (Fomichev) and *Bothrophyllum pseudoconicum* Dobrolyubova, in addition to species belonging to the genera *Paraduplophyllum* Wu *et* Zhou, *Lytvolasma* Soshkina, *Verbeekiella* Penecke and *Assimulia* Fedorowski, which are known to cross the Carboniferous/Permian boundary. These corals are associated with characteristic Late Carboniferous brachiopods like *Anthracospirifer* sp. and *Rugosochonetes californicus* Watkins. Moreovet, a rare Late Carboniferous conodont fauna dominated by *Streptognathodus* spp. was described from this interval (Omara & Kenawy 1966; Said & Eissa 1969). Some important calcareous foraminifers including *Hemigordius harltoni* Cushman *et* Waters, *Pseudobradyina* cf. *pulchra* Reitlinger, etc. were also recorded (Herbig & Kuss 1988) from this member (Fig. 5).

The middle member of the Aheimer Formation yielded an Early Permian association dominated by *Rhipidomella cordialis* Grant in addition to species of the genera *Composita* Brown and *Dielasma* King. On the other hand, a fossil flora derived from rocks overlying the Carboniferous dolostones of the Aheimer Formation at Bir Qiseib was determined by Lejal-Nicol *in* Bandel & Kuss (1987). The flora includes abundant branches of Coniferophyta and less common leaves of Pteridophylla; the sttatigraphic range of which is uppermost Carboniferous-Early Permian. A typical Permian flora dominated by *Callipteris conferta* (Sternberg) and *Cordaites* sp. were described by Lejal-Nicol (1990) ftom deposits belonging to the upper member of the Aheimer Formation in the Wadi Araba area. These deposits yielded also Early Permian fossil algae including *Ortonella morikawai* Endo, *Solenopora texana* Johnson and *Osagia incrustata* Twenhofel (Omran & Khalifa 1988).

Thus, the Aheimet Formation ranges in age from the Late Carboniferous in its lower member to the Early Permian in the upper member (Fig. 5). This age assignment is quite accepted by almost all investigatots, except Issawi (1996) who claims that the Aheimet Formation is Triassic in age.

Geographic distribution and local correlation

The Aheimer Formation is recorded in outcrops only from the western side of the Gulf of Suez. It is well exposed in the low cliffs facing the Gulf of Suez between Wadi Qiseib and Wadi Maà Sweilim. The rocks of this formation are upthrown against Cretaceous-Tertiary strata to the north of Wadi Aheimer. The landscape changed drastically in the last few years. The area is being prepared for investment; the infrastructures of many industrial and tourism projects were already constructed. Consequently, several faultblocks are destroyed and partly removed. The northernmost known outcrop (166 m thick) is that described by Swedan & Kandil (1990) from Wadi Um Reseis in the northern face of the Northern Galala. Equivalent rocks are recorded from the subsurface of the northern part of the Gulf of Suez *e.g.* Ataqa-1 and GS9-1 wells. The southernmost outcrops belonging to this unit are described from Wadi Ataba along the southern footslopes of the Northern Galala Plateau. This locality was considered as the type section of the Rod El-Hamal Formation (Abdallah & El-Adindani 1965).

The "transitional strata" exposed in the cliffs between Wadi Bir Abu Darag and Wadi Bir Abu Sandug show a general resemblance with – and are equivalent to – the upper member of the Aheimer Formation (Said & Eissa 1969). However, Abd El Shafy & Ahd El Azeam (1990) placed the "transitional strata" on top of the Aheimer Formation in spite of the absence of diagnostic fossils that may confirm such stratigraphic position. Moreover, Darwish (1992) prefered to relate all the Late Palaeozoic rocks exposed in the Northern Galala Plateau to one formal unit; the Rod El Hamal Formation, rather than to two or three formations (Fig. 4).

He considered this upper member of the Aheimer Formation ro overlie unconformably the middle member, contrary to all other investigators, and correlated it with the Jurassic-Early Cretaceous sequence of Malha Formation.

DEPOSITIONAL HISTORY AND REGIONAL CORRELATIONS

The oldest adequately dated Carboniferous deposits exposed in the Gulf of Suez region are the marine carbonates (40 m thick) of the Um Bogma Formation known only from west-central Sinai. The Early Carboniferous faunas within this phase are of subtropical character. Oxygen isotope values suggest that the water temperature was 25°-28°C (Kora 1984). Based on isopach contour maps, litho- and biofacies, it has been suggested that the Um Bogma area was submerged during Middle-Late Visean time by a shallow transgressive sea with a shoreline running generally NE-SW and an open sea towards the NW (Kora *et al.* 1994).

From the faunal assemblages, there is evidence suggesting free communication with other areas in the Tethyan Realm, even though marine time-equivalent rocks have not yet been recorded in eastern Sinai, southern Israel-Palestine nor Jordan. The probable reason for the absence of this unit from most Near East localities is a major epeirogenic uplift during the Hercynian structural event. Erosion removed most of the Early Palaeozoic and a greater part of the Early Carboniferous from eastern Egypt. Regional stratigraphic evidence indicates that this Late Devonian-Early Carboniferous event was confined to a relatively narrow belt extending from the Gulf of Suez area to the vicinity of NE Syria and SE Turkey (Kohn *et al.* 1992). Although subsequent marine transgressions affected northern Egypt, probably only marginally, no major Late Devonian-Early Carboniferous erosion is recorded in the north Western Desert of Egypt and eastern Libya (Keeley 1989).

The Um Bogma carbonates are followed by a 200 m thick clastic sequence of the Abu Thora Formation. It is a sandstone-dominated succession intercalated with some kaolinitic claystone and carbonaceous shale beds, recorded from both sides of the Gulf of Suez. The litho- and biofacies encountered reflect gradational environments between coastal marine-swampy deltaic and fluviatile (Fig. 5). The association of badly preserved brachiopods and marine trace fossils in the kaolin/coal-bearing lower member refets to a remnant of the shallow marine conditions that prevailed earlier. The carbonaceous shale intervals yielded palynofloras of Late Visean-Early Westphalian (= mostly Serpukhovian-Bashkitian) age associated with some reworked Early Palaeozoic acritarchs (Kora & Schultz 1987) and chitinozoans which may be derived originally from Late Devonian Sinaitic-Negev palaeo-high (Zaslavskaya *et al.* 1995).

The Abu Thora Formation thins towards the Abu Durba area in the south and is conformably overlain by a black shale-sandstone succession (125 m thick) of the Abu Durba Formation. This fluvio-marine to marine facies contains conodonts and brachiopods indicating a Middle Westphalian (= Early Moscovian) age. A more or less similar Carboniferous succession (175 m thick) is exposed along rhe western coastal plain of the Gulf of Suez in the Abu Darag area. Marine influence becomes less clear southwards and the equivalent deposits in the Wadi El-Dakhel section (Southern Galala) are the southernmost marine exposures in NE Africa (Jux & Issawi 1983). In the subsurface of the Gulf of Suez region, this unit is usually referred to as Nubia "B member" by most oil geologists. Fluvial sandstones increase towards Aswan and Gilf Kebir areas and the Permo-Carboniferous Gilf Formation (Fig. 4) is the equivalent rock unit in southern Egypt (Issawi & Jux 1982; Issawi & Osman 1993).

The swampy-lagoonal and deltaic intervals have yielded microfloral elements which are represented in the North African (particularly Libya, Loboziak & Clayton 1988), central and northern Saudi Arabian (Clayton 1995; Owens & Turner 1995), Western European (Clayton *et al.* 1977), North American (Ravn & Fitzgerald 1982) and Western Ausrralian (Playford & Powis 1979) palynofloras by identical or closely similar forms. This suggests that the Carboniferous vegetation

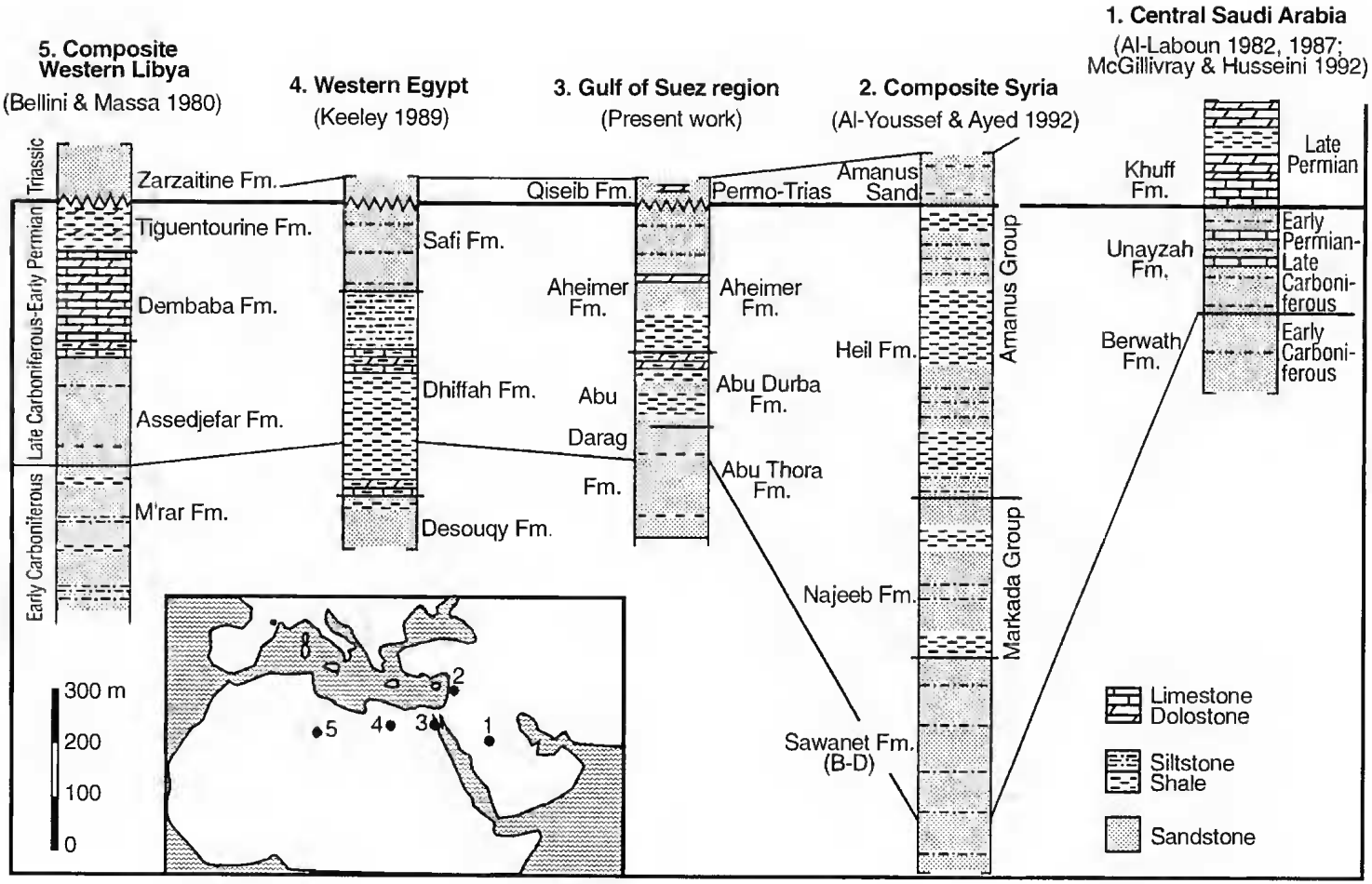

FIG. 6. — Correlation chart of the Permo-Carboniferous successions in Egypt and in some neighbouring countries.

of the Abu Thora and Abu Durba formations was of cosmopolitan nature and flourished before the Late Carboniferous glaciation in Gondwana which marked the beginning of provincialism in the floras (Kora 1993).

Outcrops in the Northern Galala are evidently of younger Carboniferous (Kazimovian-Gzhelian) and Early Permian ages. These deposits (250 m thick) reflect shallow subtidal-prograding shoreline and fluviatile conditions of the Aheimer Formation. This unit is recorded from the western side of the Gulf of Suez only and is overlain mostly by continental red beds of the Late Permian-Triassic Qiseib Formation. Equivalent deposits of the Ataqa Formation are restricted to the subsurface of the northern Gulf of Suez and central Sinai boreholes. The litho- and biofacies (Fig. 5) encountered indicate that the Aheimer Formation was deposited from a shallow transgressive-regressive sea, representing probably the last major invasion of the Tethys Sea to the area during the Palaeozoic times.

The absence of the Aheimer Formation from southern Sinai points to another uplift that took place in the region at the end of the Carboniferous or during the Early Permian. Much of the just deposited Permo-Carboniferous sediments were removed by erosion as were the remaining older deposits. The removal of the older deposits of the Abu Durba Formation from the central and northern parts of the Um Bogma area, Sinai suggests that this area was deeper truncated than the western side of the Gulf of Suez. Moreover, Carboniferous rocks have not yet been recorded in eastern Sinai, southern Israel-Palestine nor Jordan. In the Negev Desert, Early Permian clastics of the Saad Formation were recorded from the subsurface overlying the Precambrian basement and underlying thick Permo-Triassic succession (Zaslavskaya *et al.* 1995) reflecting even more deeper truncation.

In the subsurface of the northern Western Desert, Permo-Carboniferous paralic clastics equivalent to those of the Gulf of Suez include the Dhiffah and the overlying Safi formations (Fig. 6). Similar deposits are recognised from Cyrenaica in northeastern Libya (Vachard *et al.* 1993). The style of Late Palaeozoic deposition in southern Libya and into Algeria seems quite unlike that in Egypt (Keeley 1989). Equivalent deposits in western Libya basins include partly the Mrar, Assedjefar, Dembaba and Tiguentourine formations (Bellini & Massa 1980). Palaeobiogeographic relations with Tunisia, Morocco and the Algerian Sahara were stronger in the Early Carboniferous than in the Permo-Carboniferous time (Kora 1995a).

In central Saudi Arabia, the Permo-Carboniferous Unayzah Formation was recorded from Al Qasim Province and Widyan Basin (Al-Laboun 1982, 1987; Khalifa 1993). These swampy-deltaic deposits overlie conformably older Carboniferous clastics (Fig. 6) equivalent to the Khalata-Berwath formations (Owens & Turner 1995), and underlie conformably also the well-known Late Permian marine rocks of the Khuff Formation (McGillivray & Husseini 1992; Al-Aswad & Kamel 1992). These carbonate rocks represent one of the largest outcrops of marine Permian in the world, with clastics increasing southwards.

The Permo-Carboniferous sandstones are recorded also in the Mosandam Peninsula of northern Oman (Gharif Formation) and from western Iran (Faraghan Formation), underlying conformably Late Permian carbonates (Khalifa 1993). In the Western Iraqi Desert, equivalent Permo-Carboniferous clastics have been described as the Gaara Formation (Nader *et al.* 1993, 1994) reflecting also swampy-fluviatile conditions. Time-equivalent rocks in Syria (Fig. 6) include shallow marine-deltaic subsurface deposits of the Markada Group (Sawanet and Najeeb formations) and continental clastics of the Amanus Group (Heil Formation). If the thicknesses estimated by Al-Youssef & Ayed (1992) are correct, then the Syrian Permo-Carboniferous deposits (>1000 m in the Palmyrid Trough) will be the thickest succession ever recorded in the Middle East. Equivalent less developed deposits have also been recorded from SE Turkey and northern Iraq.

CONCLUSION

A unified lithostratigraphic scheme for the Late Palaeozoic succession in the Gulf of Suez region

is proposed, including from base to top:
– Um Bogma Formation: Middle-Late Visean,
– Abu Thora Formation: mostly Serpukhovian-Bashkirian,
– Abu Durba Formation: Moscovian,
– Aheimer Formation: Kazimovian/Gzhelian-Early Permian,
– Qiseib Formation: Late Permian-Triassic.
The Um Bogma Formation is known only from the eastern side and the Aheimer Formation is recorded only from the western side of the gulf; all other formations are distributed on both sides.

In spite of the fact that both the Abu Thora and the overlying Abu Durba formations, which are originally described from Sinai, do occur on the western side of the Gulf of Suez, the complicated structural pattern of the Abu Darag-Wadi Araba area makes it difficult to differentiate in the field between the clastics building up these two formations. In that case, the name Abu Darag Formation can be applied for the Carboniferous succession exposed in that particular area.
The Carboniferous-Permian succession in the region is bounded by two unconformities; a pronounced lower one, coinciding with the Hercynian structural event, resulted in the removal of most of the underlying Early Palaeozoic and the basal Early Carboniferous deposits. The second uplift took place mostly during the Early Permian and led to subsequent erosion of a part of the Late Carboniferous and all the Early Permian successions from Sinai. It seems that the Late Permian sea transgression which covered wide areas in the Near East had not affected Egypt, since continental red beds (the Qiseib Formation) of Late Permian-Triassic age overlie unconformably the Permo-Carboniferous succession.
The fossil communities indicate that the Permo-Carboniferous succession of the Gulf of Suez region was deposited during transgressive/regressive cycles of a subtropical epicontinental sea which might have covered the northern parts of the Eastern and Western Deserts of Egypt, eastern Libya and greater areas in North Africa. The swampy-lagoonal and deltaic intervals in the Late Carboniferous succession can be correlated with equivalent deposits from northern and central Saudi Arabia, Syria and other countries in the Near East. Since no marine Permo-Carboniferous deposits are recorded south of the study area, it can be concluded that the Gulf of Suez region and greater areas in North Africa and the Near East were situated not far from the southern shore of the Tethys Sea during most of the Permo-Carboniferous time.
The current knowledge of the Permo-Carboniferous fauna of the Gulf of Suez region, though containing enough elements pointing to a free communication with the thicker marine Tethyan sequences, is still far from complete. Excessive investigation of the marine layers in the Abu Thora, Abu Durba and Aheimer formations may result in the recognition of more distinctive fossils. Conodonts and calcareous foraminifers are necessary microfaunas in calibrating the biostratigraphic and palaeogeographic interpretations.

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